

EXHIBIT A

Please delete the specification in its entirety and replace with the following:

--METHOD AND SYSTEM FOR THREE-DIMENSIONAL HANDWRITING RECOGNITION

BACKGROUND OF THE INVENTION

The invention relates generally to handwriting recognition technologies, and more particularly to three-dimensional (3D) handwriting recognition methods and systems.

Handwriting recognition is a technique by which an intelligence system can recognize characters and other symbols written by hand. This technique has been very popular since it frees users from the keyboard, allowing users to write and draw in a more natural way. With the increasing demands from users, more and more devices now have incorporated handwriting recognition system to give users natural input experience. Handwriting recognition is particularly popular in various handheld devices that provides handwriting recognition of words with complex structures, e.g.,

Chinese characters, input of which using a conventional keyboard is very time consuming.

5 A handwriting input device provides a user with a friendly way of inputting information. At present, the minimum requirement for an inputting device is a mouse. To write with the mouse, the user needs to press and hold down the primary mouse button, and then move the mouse pointer to form strokes of a word or character for generating the final word or character. Popular handwriting input devices, such as a pen stylus and tablet, are used on conventional handheld devices such as PDAs, or
10 are connected to a computer through a serial or USB port. Handheld devices often use a pen stylus and a touch screen as a pad to allow users to perform recognition functions. Most handheld devices, such as PDAs, are equipped with this kind of input device.

15 Another kind of handwriting input device includes a pen that allows users to transfer data into a receiving unit, such as a cellular phone, a PDA or a PC by simply writing or drawing in their own natural handwriting on the comfort and space of a regular piece of paper.

20 At present, all conventional handwriting input devices adopt a two-dimensional input method. Users have to write on a physical medium, such as a tablet, a touch screen, or a paper pad. This limits the choices available for users. For example, if a user wants to write some comments during a presentation or a lecture, he or she

would have to first find a physical medium, e.g., a table, a paper pad, etc. This can cause much inconvenience for the user while standing in the room, giving the presentation or lecture. Also, in a mobile environment, such as in a car, a bus or a subway, it would be very inconvenient to “write” on a physical medium using a stylus.

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Therefore, there is a need to provide an improved handwriting recognition system that gives users more flexibility and convenience and frees the users from the physical medium required for two-dimensional handwriting recognition.

SUMMARY OF THE INVENTION

The present invention gives users more flexibility and enjoyable writing experience by allowing users to freely write words or characters in a 3D space in a touchless way, without requiring any physical medium such as a pad or a tablet.

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According to the invention, there is provided a handwriting recognition system that comprises an input device and a recognition device in communication with the input device. The input device includes a three-dimensional (3D) motion detection sensor configured to generate 3D motion data in response to a 3D motion. In one
10 embodiment, the motion detection sensor measures acceleration of the 3D motion in X, Y and Z axial directions to generate the 3D motion data. The recognition device is configured to receive (e.g., by wireless means) the 3D motion data from the input device and derive corresponding two-dimensional (2D) images for handwriting recognition, based on the 3D motion data.

15 According to one embodiment of the invention, the recognition device calculates corresponding 3D coordinates based on the 3D motion data, constructs corresponding 3D tracks based the 3D coordinates, and derives the corresponding 2D images from the 3D tracks by mapping the 3D tracks onto a 2D plane for handwriting recognition.

Other objects and attainments together with a fuller understanding of the
20 invention will become apparent and appreciated by referring to the following description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in further detail, and by way of example, with reference to the accompanying drawings wherein:

FIG. 1 shows a three-dimensional handwriting recognition system according to one embodiment of the invention;

FIG. 2 is a flow chart diagram illustrating a recognition process according to one embodiment of the invention;

FIG. 3A shows a 2D image of a Chinese character derived by mapping 3D tracks onto a 2D projection plane;

FIG. 3B shows a final result of handwriting recognition process based on the 2D image in FIG. 3A;

FIG. 4 shows an external design of a 3D handwriting input device according to one embodiment of the invention; and

FIG. 5 illustrates how the input device may be mounted.

Throughout the drawings, the same reference numerals indicate similar or corresponding features or functions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a three-dimensional handwriting recognition system 10 according to one embodiment of the invention. As illustrated, system 10 comprises a handwriting input device 20, a recognition device 30 and an output device 40. Input device 20 includes a 3D motion detection sensor 22, a control circuit 26 and a communication interface 28. Recognition device 30 includes a processor 32, a memory 34, a storage device 36, and a communication interface 38. For simplicity, other conventional elements are not shown in FIG. 1.

In operation, a user moves input device 20 to freely write words or characters in a 3D space, e.g., in the air. Motion detection sensor 22 detects the 3D motion and communicates the 3D motion data and a sampling rate to recognition device 30 for handwriting recognition via a communication interface 28, such as Bluetooth, Zigbee, IEEE 802.11, infrared, or a USB port. The sampling rate may be a predetermined value set by an end user or a manufacturer based on factors such as the processing capability of the system. Alternatively, the sampling rate may be dynamically determined and adjusted based on, for example, the speed of the motion. This can be done, for example, by first determining the speed of the initial motion associated with the handwriting. Then the recognition device can dynamically adjust the sampling rate based on the speed of the motion at the last sampling point. The higher the speed is, the higher the sampling rate will be, and vice versa. By dynamically adjusting the sampling rate, the accuracy of the handwriting recognition can be improved since only

the optimal number of sampling points will be used for constructing the word or character. Further, lower power consumption is needed.

Based on the motion data and the sampling rate received from input device 20,
5 processor 32 calculates the corresponding 3D coordinates on the X, Y and Z axes and stores these coordinates in storage device 36. Using the calculated coordinates, processor 32 constructs the corresponding 3D tracks. The 3D tracks will then be projected onto a 2D plane to form 2D images which will be recognized using conventional handwriting recognition software. The final result is displayed on output
10 device 40.

Since 3D writing is a continuous process, control circuit 26 of input device 20 provides a control signal to recognition device 30 via interface 28 to indicate separation of individual words or characters upon receiving a user provided external
15 input. For example, the user may press a control button to cause control circuit 26 to generate the control signal after completion of writing a word or a character.

According to a specific embodiment of the invention, motion detection sensor 22 detects the 3D motion by measuring the acceleration of the movement along the X,
20 Y and Z axes. As an example, the piezoresistive-type tri-axial accelerating sensor commercially available from Hitachi Metals, Ltd., Tokyo, Japan, may be used as motion detection sensor 22. This accelerating sensor in the form of an IC chip has the ability to simultaneously detect acceleration in the three axial directions (X, Y and Z).

The sensor is highly sensitive and shock resistant and is a very small and thin semiconductor type 3 axial accelerating sensor. More information about this accelerating sensor is available on the following website http://www.hitachi-metals.co.jp/e/prod/prod06/p06_10.html, which is hereby incorporated by reference.

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FIG. 2 is a flow chart diagram illustrating a recognition process 100 performed by recognition device 30, according to one embodiment of the invention. In FIG. 2, recognition device 30 receives the 3D motion data (e.g., the acceleration data of the movement in the X, Y and Z directions) and the sampling rate from input device 20 (step 102). Based on the information received, processor 32 calculates the corresponding 3D coordinates on the X, Y and Z axes for each sampling point using the starting point of the movement as the origin (step 106). Each sampling point is also used as a reference point for calculating the coordinates of the following sampling point.

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Calculation of the 3D coordinates is continuously performed based on the incoming 3D motion data until processor 32 detects receipt of a control signal (step 112). The control signal indicates completion of writing a word or a character. The corresponding 3D tracks are constructed using the 3D coordinates (step 116) and are then mapped onto a 2D plane (step 122). Thereafter, conventional 2D handwriting recognition is performed (step 126).

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In the above recognition process 100, to map the 3D tracks onto a 2D plane at step 122, it is necessary to first find a proper 2D projection plane. In a preferred embodiment of the invention, a proper 2D projection plane is separately derived for each word or character.

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According to the geometry principles, a proper 2D projection plane is a plane, to which the sum of the distance square of each sampling point is minimal. Assume the coordinates of n sampling points are known as follows:

10 $(x_1, y_1, z_1), (x_2, y_2, z_2) \dots (x_n, y_n, z_n)$, and the equation of the plane is $Ax + By + Cz + D = 0$, where $(A^2 + B^2 + C^2 \neq 0)$. Now it is necessary to determine the values of A, B, C, D . The distance from one point (x_1, y_1, z_1) to the plane is given as

$d_1 = \frac{|Ax_1 + By_1 + Cz_1 + D|}{\sqrt{A^2 + B^2 + C^2}}$, and the sum $\sum_{i=1}^n d_i^2$ represented by $F(A, B, C, D)$ is

expressed as:

$$F(A, B, C, D) = \sum_{i=1}^n d_i^2 = \frac{(Ax_1 + By_1 + Cz_1 + D)^2 + (Ax_2 + By_2 + Cz_2 + D)^2 + \dots + (Ax_n + By_n + Cz_n + D)^2}{A^2 + B^2 + C^2}$$

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The values of A, B, C, D can be determined using the Lagrange multiplication method as follows, which is described in *Mathematics Analysis* by Ouyang Guangzhong, published by Fudan University Press in 1999 in China, which is hereby incorporated by reference. Thus,

20 $F(A, B, C, D) = F'(A, B, C, D) = (Ax_1 + By_1 + Cz_1 + D)^2 + (Ax_2 + By_2 + Cz_2 + D)^2 + \dots + (Ax_n + By_n + Cz_n + D)^2$

under the constraint $A^2 + B^2 + C^2 = 1$. From this equation, the following equation is derived:

$$G(A, B, C, D) = F'(A, B, C, D) + \lambda(A^2 + B^2 + C^2 - 1),$$

where λ is a Lagrange multiplier, which is a constant. The partial differential functions

5 are now performed on $G(A, B, C, D)$ with respect to A, B, C and D as follows:

$$\begin{aligned}\frac{\partial G(A, B, C, D)}{\partial A} &= 0 \\ \frac{\partial G(A, B, C, D)}{\partial B} &= 0 \\ \frac{\partial G(A, B, C, D)}{\partial C} &= 0 \\ \frac{\partial G(A, B, C, D)}{\partial D} &= 0\end{aligned}$$

From the above four equations, the following equations are obtained:

$$A(\sum_{i=1}^n (x_i * x_i) + \lambda) + B\sum_{i=1}^n (x_i * y_i) + C\sum_{i=1}^n (x_i * z_i) + D\sum_{i=1}^n x_i = 0 \quad (1)$$

$$A\sum_{i=1}^n (x_i * y_i) + B(\sum_{i=1}^n (y_i * y_i) + \lambda) + C\sum_{i=1}^n (y_i * z_i) + D\sum_{i=1}^n y_i = 0 \quad (2)$$

$$A\sum_{i=1}^n (x_i * z_i) + B\sum_{i=1}^n (z_i * y_i) + C(\sum_{i=1}^n (z_i * z_i) + \lambda) + D\sum_{i=1}^n z_i = 0 \quad (3)$$

$$A\sum_{i=1}^n x_i + B\sum_{i=1}^n y_i + C\sum_{i=1}^n z_i + nD = 0 \quad (4)$$

$$A^2 + B^2 + C^2 = 1 \quad (5)$$

where equation (4) can be rewritten as:

$$D = -\frac{1}{n}(A\sum_{i=1}^n x_i + B\sum_{i=1}^n y_i + C\sum_{i=1}^n z_i) \quad (6)$$

By incorporating equation (6) into equations (1), (2), and (3), the following is obtained:

$$\begin{bmatrix} \sum_{i=1}^n (x_i * x_i) - \frac{1}{n} \sum_{i=1}^n (x_i * x_i) & \sum_{i=1}^n (x_i * y_i) - \frac{1}{n} \sum_{i=1}^n (x_i * y_i) & \sum_{i=1}^n (x_i * z_i) - \frac{1}{n} \sum_{i=1}^n (x_i * z_i) \\ \sum_{i=1}^n (x_i * y_i) - \frac{1}{n} \sum_{i=1}^n (x_i * y_i) & \sum_{i=1}^n (y_i * y_i) - \frac{1}{n} \sum_{i=1}^n (y_i * y_i) & \sum_{i=1}^n (z_i * y_i) - \frac{1}{n} \sum_{i=1}^n (z_i * y_i) \\ \sum_{i=1}^n (x_i * z_i) - \frac{1}{n} \sum_{i=1}^n (x_i * z_i) & \sum_{i=1}^n (z_i * y_i) - \frac{1}{n} \sum_{i=1}^n (z_i * y_i) & \sum_{i=1}^n (z_i * z_i) - \frac{1}{n} \sum_{i=1}^n (z_i * z_i) \end{bmatrix} * \begin{bmatrix} A \\ B \\ C \end{bmatrix} = -\lambda \begin{bmatrix} A \\ B \\ C \end{bmatrix} \quad (7)$$

Thus, from the above equations, the values of A, B, C and D can be obtained.

As an example, the following 3D coordinates for a total of 13 sampling points

5 are obtained for a Chinese character:

{(0,0,0),(0.49,-1,0.02),(1,0,0.03),(0,0,0.02),(2,-0.13,0.01),(3.5,-0.14,0),(3.76,-0.31,-
0.01),(2.74,-1.26,0.01),(1.38,-2.24,0),(2.5,-2,0.01),(1.746,1,0.02),(2,-1.5,0.03),(1.876,-
4.5,0.02),}.

10 By using the Lagrange multiplication method described above, the following are obtained:

$$\begin{bmatrix} 53.407 & -23.6725 & 0.1911 \\ -23.6725 & 36.2195 & -0.2084 \\ 0.1911 & -0.2084 & 0.0035 \end{bmatrix} * \begin{bmatrix} A \\ B \\ C \end{bmatrix} = -\lambda \begin{bmatrix} A \\ B \\ C \end{bmatrix},$$

$$A^2 + B^2 + C^2 = 1, \text{ and}$$

$$D = -\frac{1}{13}(A \sum x_i + B \sum y_i + C \sum z_i).$$

15 From the above equations, the values of A, B, C and D are determined as follows:

$$A = 0.0045, B = 0.0023, C = 0.9999, D = -0.01777.$$

Thus, the equation of the 2D projection plane is $0.0045x + 0.0023y + 0.9999z - 0.01777 = 0$. From the equation of the projection plane,

$Ax + By + Cz + D = 0$, and the equation of a line that is vertical to the projection plane,

$\frac{x - x_i}{A} = \frac{y - y_i}{B} = \frac{z - z_i}{C}$, the following equations are derived:

$$x = \frac{(B^2 + C^2)x_i - A(By_i + Cz_i + D)}{A^2 + B^2 + C^2}$$

$$y = \frac{(A^2 + C^2)y_i - B(Ax_i + Cz_i + D)}{A^2 + B^2 + C^2}$$

5 which can be used to obtain the corresponding 2D coordinates for each 3D sampling point. In this example, the following corresponding 2D coordinates are obtained:

{(0.0001,0),(0.49,-1),(1,-2.0001),(0,0),(2,-0.13),(3.5001,-0.14),(3.7601,-0.31),(2.7401,-1.26),(1.3801,2.24),(2.5001,-2),(1.746,1),(2,-1.5001),(1.876,-4.5001)}.

Based on these 2D coordinates, the corresponding 2D image is projected onto the 2D

10 projection plane. The result of this Chinese character is shown in FIG. 3A. The final result is generated by performing a conventional 2D handwriting recognition process, as shown in FIG. 3B.

In the above, the Lagrange multiplication method is used to obtain the values of

15 A, B, C and D. Other methods such as linear regression method may also be used.

FIG. 4 shows an external design of a 3D handwriting input device 200 according to one embodiment of the invention. As shown in FIG. 4, input device 200 includes a housing 210 that contains the electronics parts of the device (such as a 3D
20 motion detection sensor IC chip), a control button 212 for allowing a user to input a

control signal to indicate completion of writing a word or character, and a band 220 for mounting input device 200 on the user's finger.

FIG. 5 illustrates how input device 200 may be mounted. In FIG. 5, device 200 is mounted on a finger 232 of a user's hand 230. By mounting it on the finger, the user can simply move the finger to write any word or character in a 3D space. The 3D motion data will be wirelessly transmitted to a recognition device for handwriting recognition.

According to the invention, the input device and the recognition device can be integrated together as a single unit (e.g., a pen) that operates in the same manner as described above. The final recognition results will be transmitted to an intelligent apparatus such as a PDA, a laptop computer, a PC, etc.

The invention can also be used on a 2D plane if the user so chooses. In such a case, the coordinates calculated will be for 2D plane and the step of mapping the 3D tracks onto a 2D plane is omitted.

While the invention has been described in conjunction with specific embodiments, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications and variations as fall within the spirit and scope of the appended claims.